Prior

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Girerd et al.

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[45] Date of Patent: *Oct. 10, 2000

[54] CLIENT-SERVER BASED REMOTE LOCATOR DEVICE

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[73] Assignee: **SnapTrack, Inc.**, San Jose, Calif.

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[21] Appl. No.: **08/708,176**

[22] Filed: **Sep. 6, 1996**

Related U.S. Application Data

[60] Provisional application No. 60/005,318, Oct. 9, 1995.

[51] **Int. Cl.**[7] **G06F 17/00**

[52] **U.S. Cl.** **701/213**; 340/989

[58] **Field of Search** 395/200.33, 200.47, 395/200.48, 200.49; 364/449.1, 449.2, 449.7, 449.9, 460; 701/207, 208, 213, 214, 215, 300; 342/352, 357, 419, 457; 340/988, 989, 990, 993, 995

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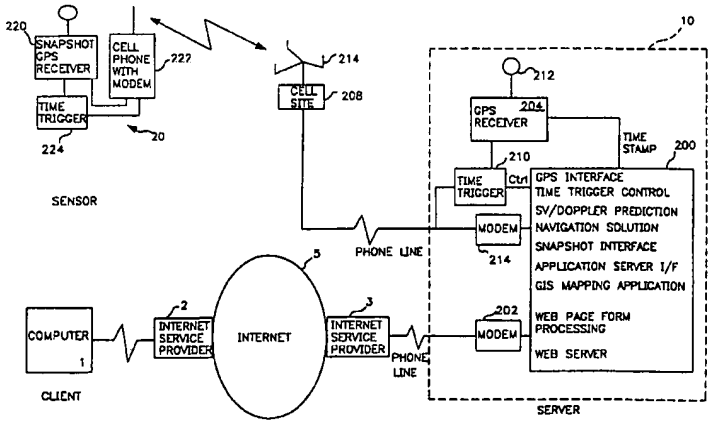
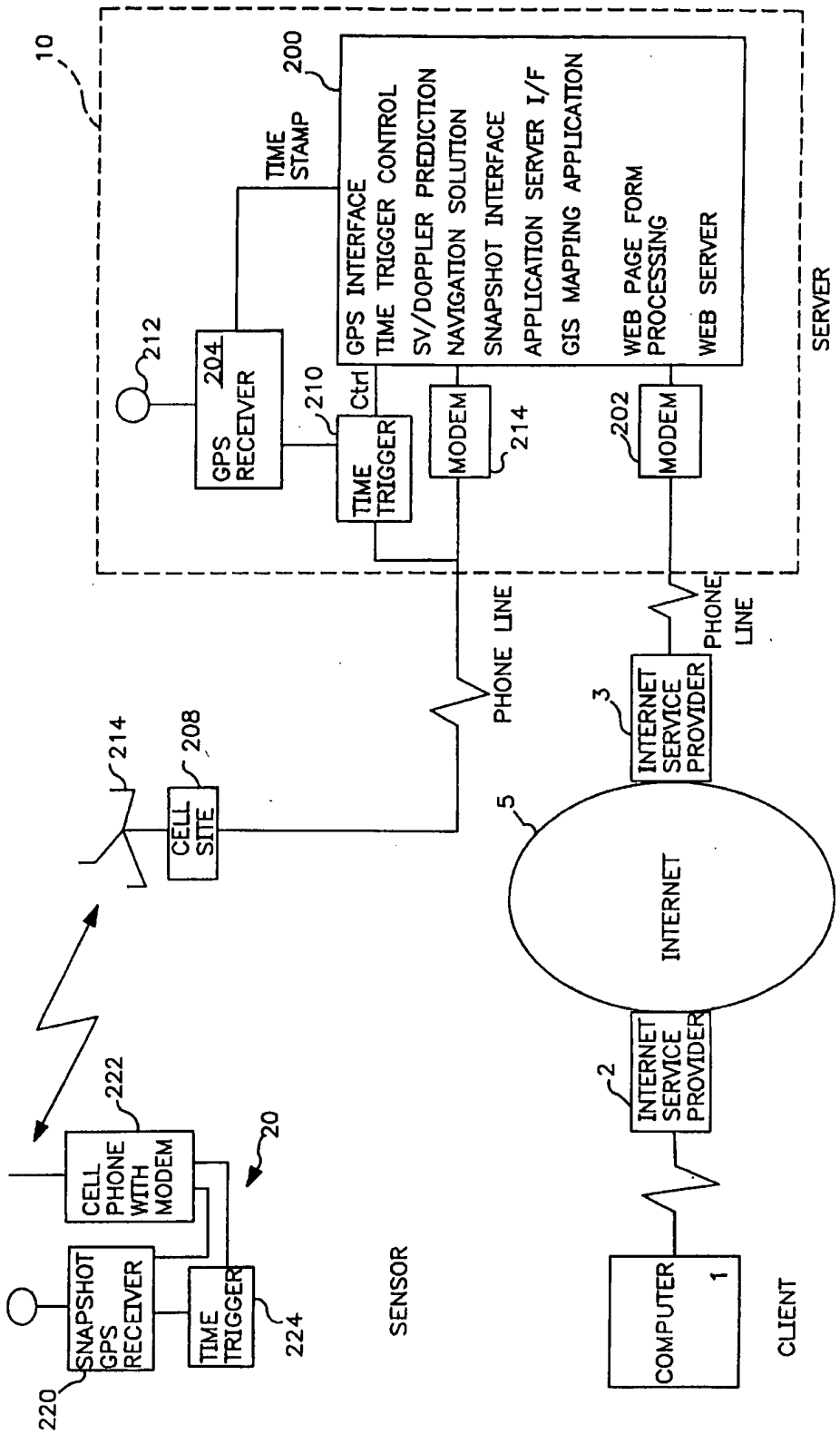
Assistant Examiner—Edward Pipala
Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman

[57] **ABSTRACT**

A user accesses a server using a client. The client provides an identification code which serves to uniquely identify a remote sensor. The remote sensor is capable of providing information related to its position. The server interrogates the remote sensor and, in response, the remote sensor transmits positioning data to the server where it is analyzed to derive the location of the remote server. The location so determined is transmitted from the server to the client and is displayed at the client so that the user can identify the location of the remote sensor. The client and the server may be connected to a computer network and the client may use a web browser to interrogate the server. The remote sensor may be a SNAPSHOT GPS receiver or other GPS receiver or positioning device. The user display may be a simple position report, e.g., latitude and longitude, or a graphical report which provides an indication of the remote sensor's location superimposed on a map or other reference.

40 Claims, 10 Drawing Sheets

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200
TIME STAMP
GPS INTERFACE
TIME TRIGGER CONTROL
SV/DOPPLER PREDICTION
NAVIGATION SOLUTION
SNAPSHOT INTERFACE
APPLICATION SERVER I/F
GIS MAPPING APPLICATION
WEB PAGE FORM PROCESSING
WEB SERVER
SERVER
212
204
GPS RECEIVER
210
Ctrl
TIME TRIGGER
MODEM
214
202
MODEM
PHONE LINE
PHONE LINE
214
208
CELL SITE
3
INTERNET SERVICE PROVIDER
5
INTERNET
2
INTERNET SERVICE PROVIDER
222
CELL PHONE WITH MODEM
20
SNAPSHOT GPS RECEIVER
TIME TRIGGER
224
220
SENSOR
COMPUTER
1
CLIENT

FIG. 1A

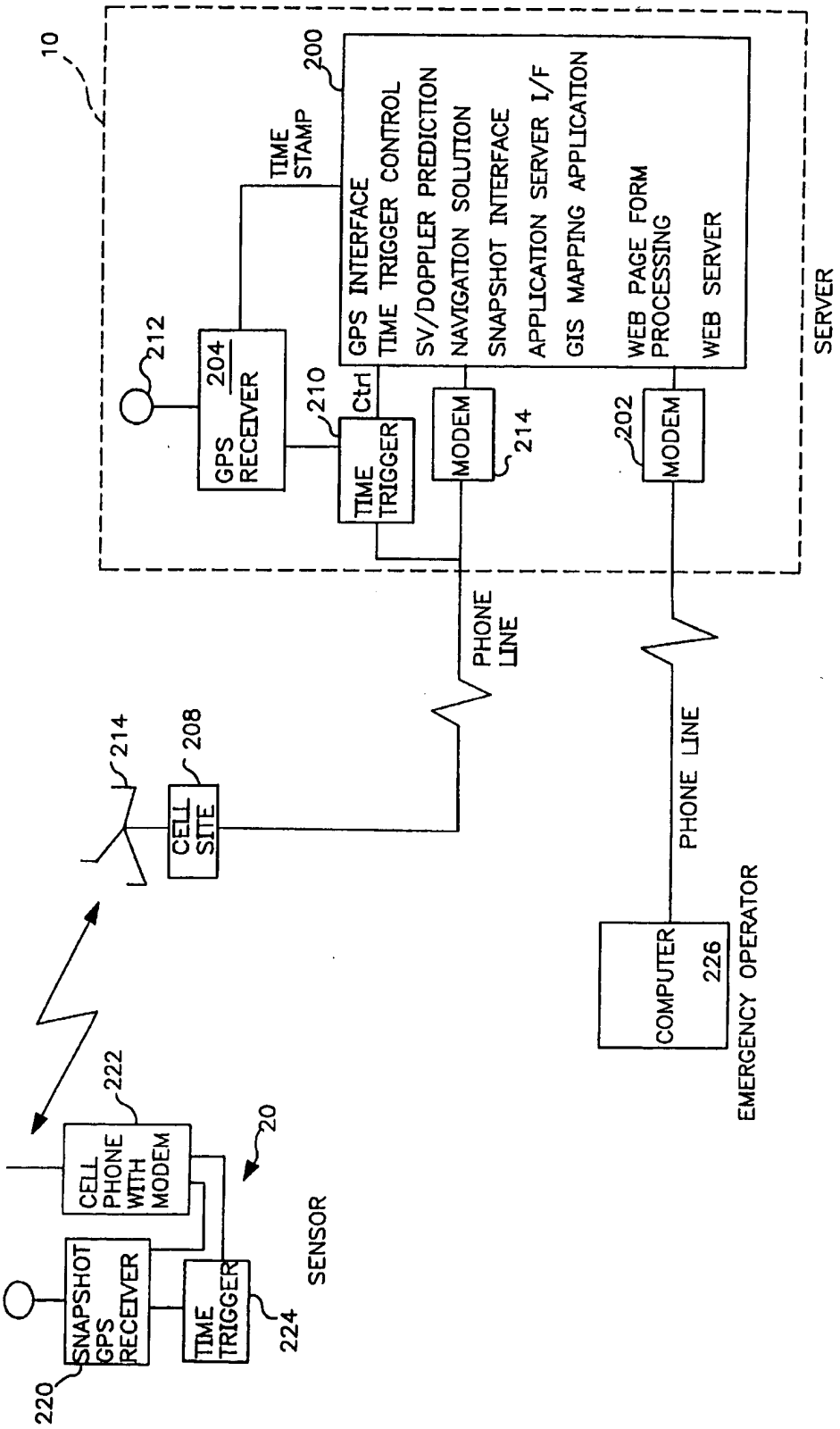
10
200
GPS INTERFACE
TIME TRIGGER CONTROL
SV/DOPPLER PREDICTION
NAVIGATION SOLUTION
SNAPSHOT INTERFACE
APPLICATION SERVER I/F
GIS MAPPING APPLICATION
WEB PAGE FORM PROCESSING
WEB SERVER
SERVER
TIME STAMP
212
GPS RECEIVER
204
210
Ctrl
TIME TRIGGER
MODEM
214
202
MODEM
PHONE LINE
214
208
CELL SITE
PHONE LINE
COMPUTER
226
EMERGENCY OPERATOR
222
CELL PHONE WITH MODEM
20
SNAPSHOT GPS RECEIVER
TIME TRIGGER
224
220
SENSOR

FIG. 1B

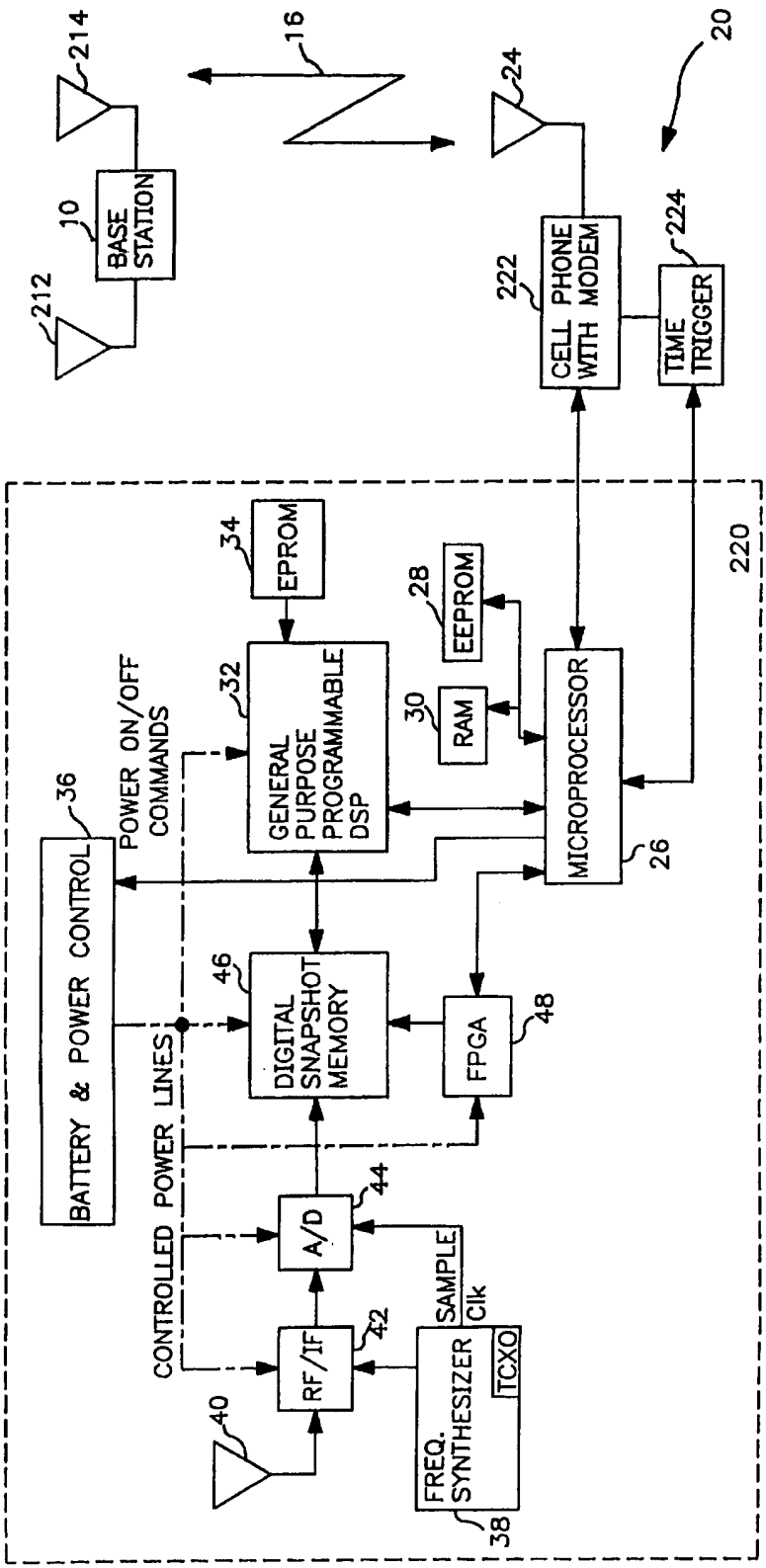
214
16
20
24
BASE STATION
10
212
222
CELL PHONE WITH MODEM
224
TIME TRIGGER
220
34
EPROM
28
EEPROM
32
GENERAL PURPOSE PROGRAMMABLE DSP
30
RAM
MICROPROCESSOR
26
POWER ON/OFF COMMANDS
36
BATTERY & POWER CONTROL
46
DIGITAL SNAPSHOT MEMORY
FPGA
48
CONTROLLED POWER LINES
A/D
44
SAMPLE Clk
RF/IF
42
TCXO
40
FREQ. SYNTHESIZER
38

FIG. 2

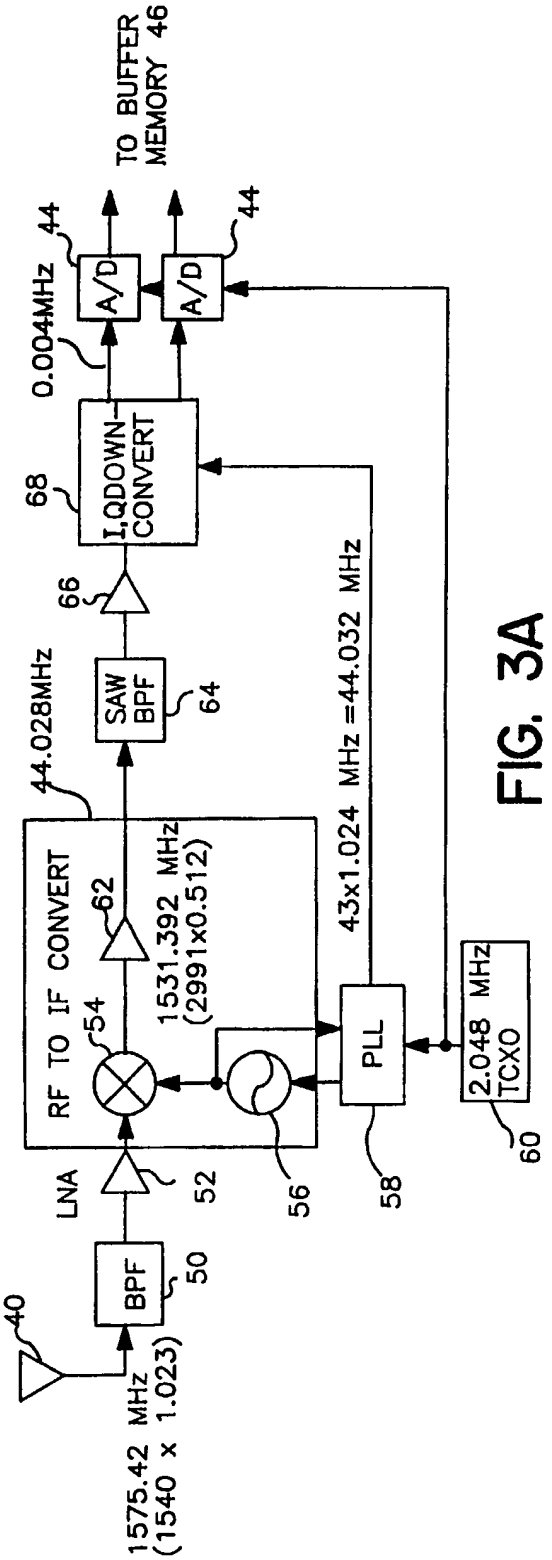
TO BUFFER MEMORY 46
44
44
A/D
A/D
0.004MHz
68
I,QDOWN CONVERT
66
SAW BPF
64
44.028MHz
RF TO IF CONVERT
62
54
1531.392 MHz (2991x0.512)
43x1.024 MHz =44.032 MHz
PLL
2.048 MHz TCXO
60
58
56
LNA
52
BPF
50
40
1575.42 MHz (1540 x 1.023)

FIG. 3A

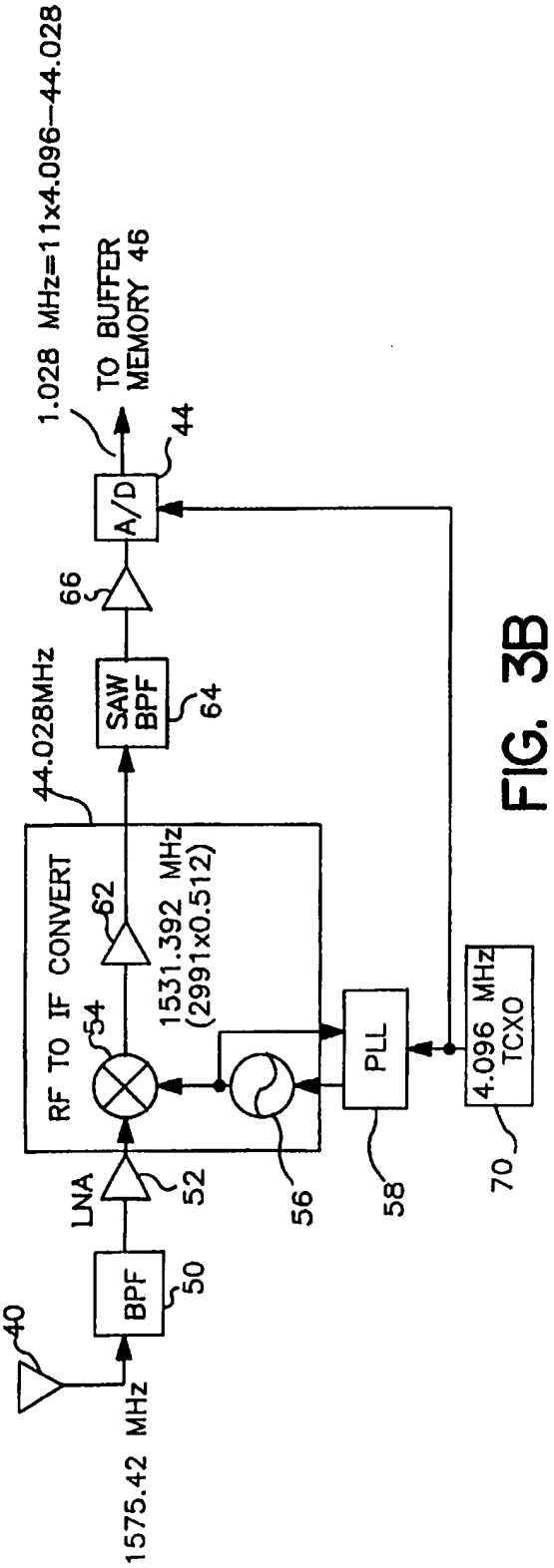
1575.42 MHz
40
BPF
50
LNA
52
RF TO IF CONVERT
54
62
1531.392 MHz
(2991x0.512)
44.028MHz
SAW
BPF
64
66
A/D
44
1.028 MHz=11x4.096-44.028
TO BUFFER
MEMORY 46
56
PLL
58
4.096 MHz
TCXO
70

FIG. 3B

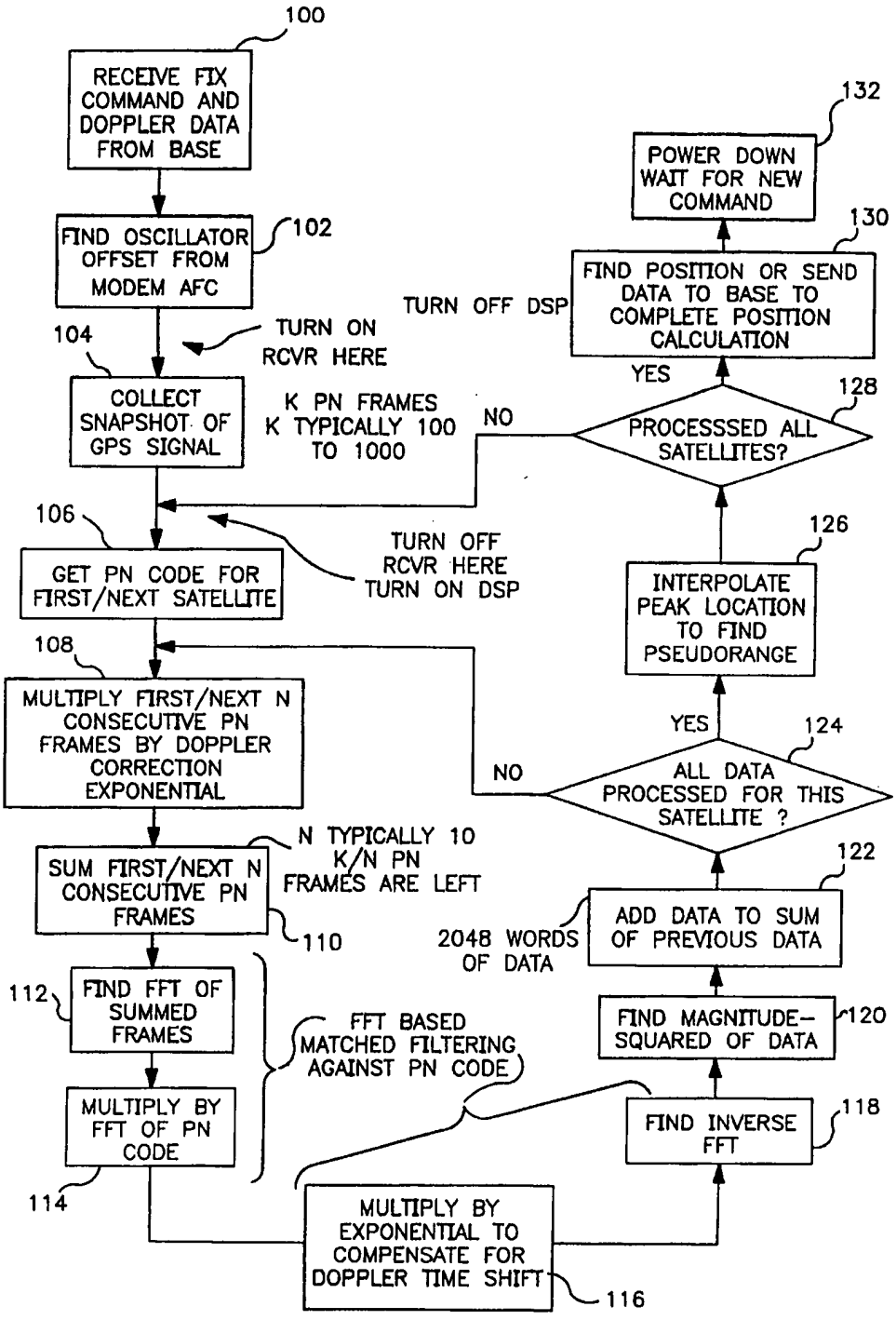
100
RECEIVE FIX COMMAND AND DOPPLER DATA FROM BASE
102
FIND OSCILLATOR OFFSET FROM MODEM AFC
104
TURN ON RCVR HERE
COLLECT SNAPSHOT OF GPS SIGNAL
K PN FRAMES K TYPICALLY 100 TO 1000
106
GET PN CODE FOR FIRST/NEXT SATELLITE
TURN OFF RCVR HERE TURN ON DSP
108
MULTIPLY FIRST/NEXT N CONSECUTIVE PN FRAMES BY DOPPLER CORRECTION EXPONENTIAL
SUM FIRST/NEXT N CONSECUTIVE PN FRAMES
N TYPICALLY 10 K/N PN FRAMES ARE LEFT
110
112
FIND FFT OF SUMMED FRAMES
MULTIPLY BY FFT OF PN CODE
114
FFT BASED MATCHED FILTERING AGAINST PN CODE
MULTIPLY BY EXPONENTIAL TO COMPENSATE FOR DOPPLER TIME SHIFT
116
FIND INVERSE FFT
118
FIND MAGNITUDE-SQUARED OF DATA
120
2048 WORDS OF DATA
ADD DATA TO SUM OF PREVIOUS DATA
122
ALL DATA PROCESSED FOR THIS SATELLITE ?
124
NO
YES
INTERPOLATE PEAK LOCATION TO FIND PSEUDORANGE
126
PROCESSSED ALL SATELLITES?
128
NO
YES
TURN OFF DSP
FIND POSITION OR SEND DATA TO BASE TO COMPLETE POSITION CALCULATION
130
POWER DOWN WAIT FOR NEW COMMAND
132

FIG. 4

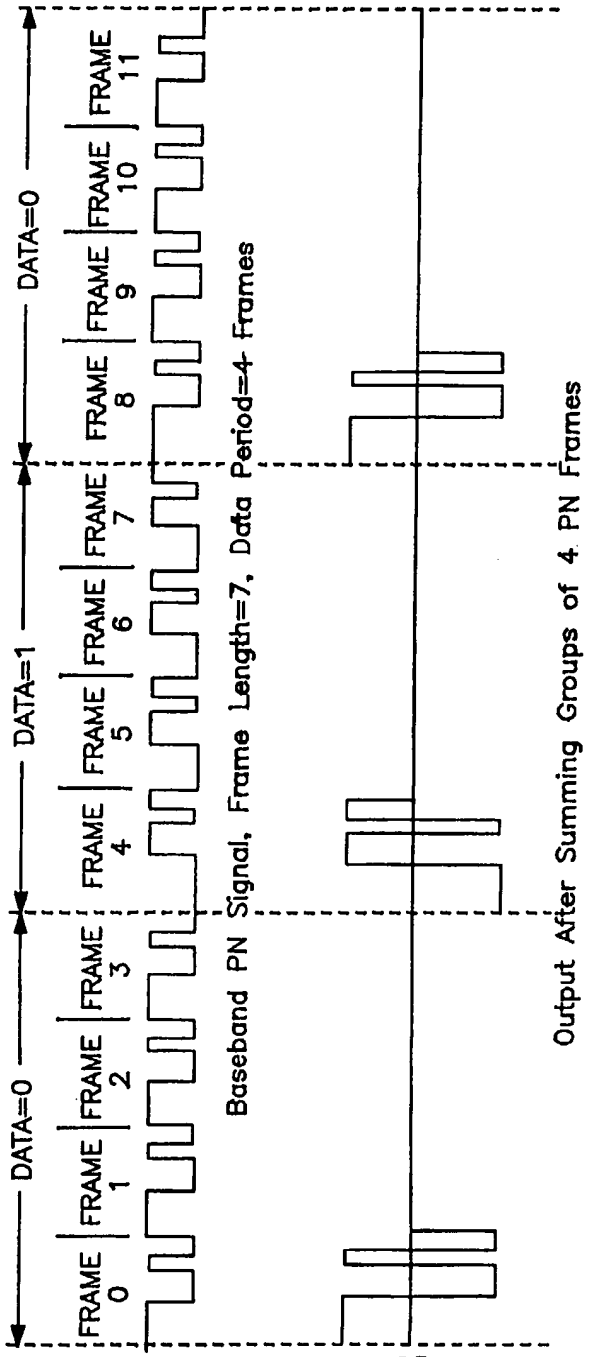
DATA=0
DATA=1
DATA=0
FRAME 0
FRAME 1
FRAME 2
FRAME 3
FRAME 4
FRAME 5
FRAME 6
FRAME 7
FRAME 8
FRAME 9
FRAME 10
FRAME 11
Baseband PN Signal, Frame Length=7, Data Period=4 Frames
Output After Summing Groups of 4 PN Frames

FIG. 5A

FIG. 5B

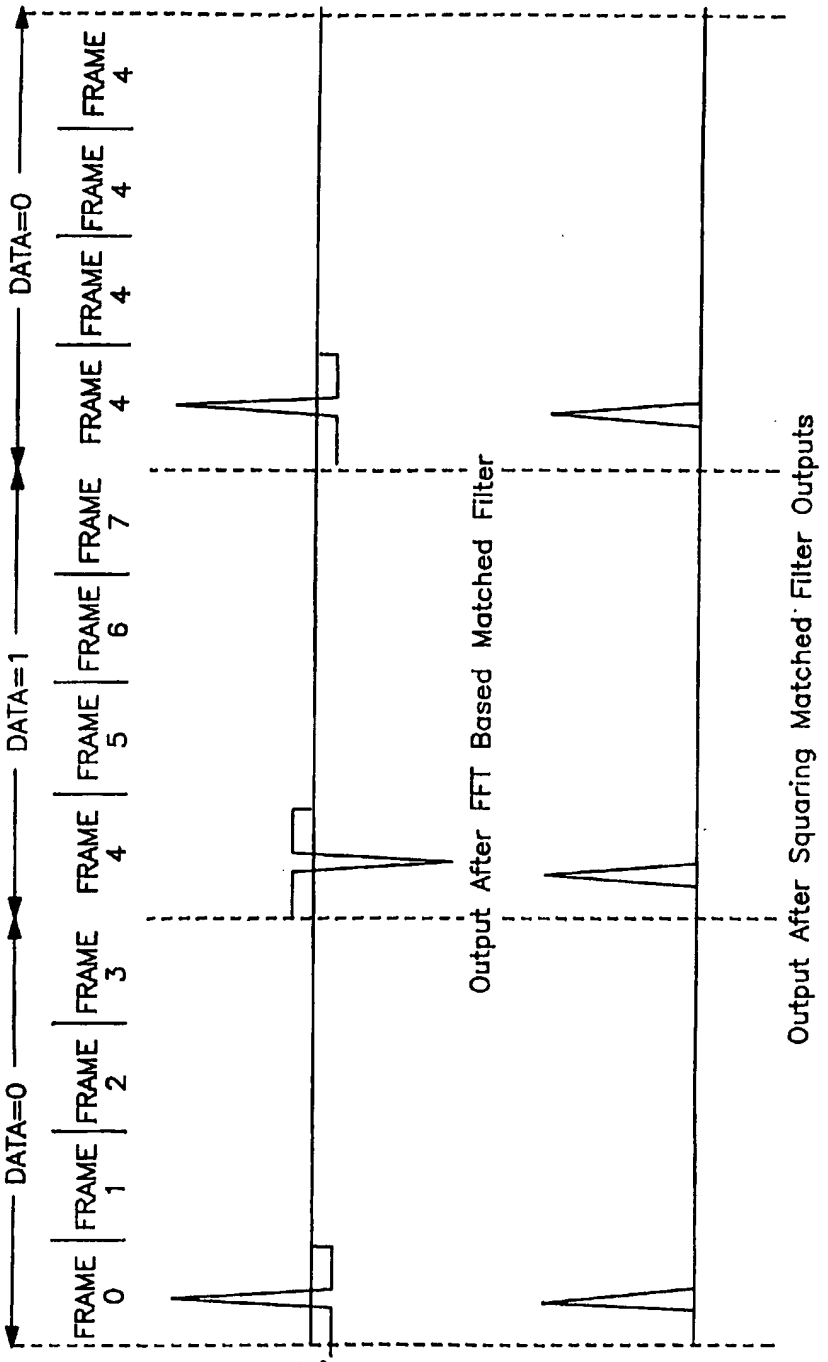
DATA=0
DATA=1
DATA=0
FRAME 0
FRAME 1
FRAME 2
FRAME 3
FRAME 4
FRAME 5
FRAME 6
FRAME 7
FRAME 4
FRAME 4
FRAME 4
FRAME 4
Output After FFT Based Matched Filter
Output After Squaring Matched Filter Outputs

FIG. 5C FIG. 5D

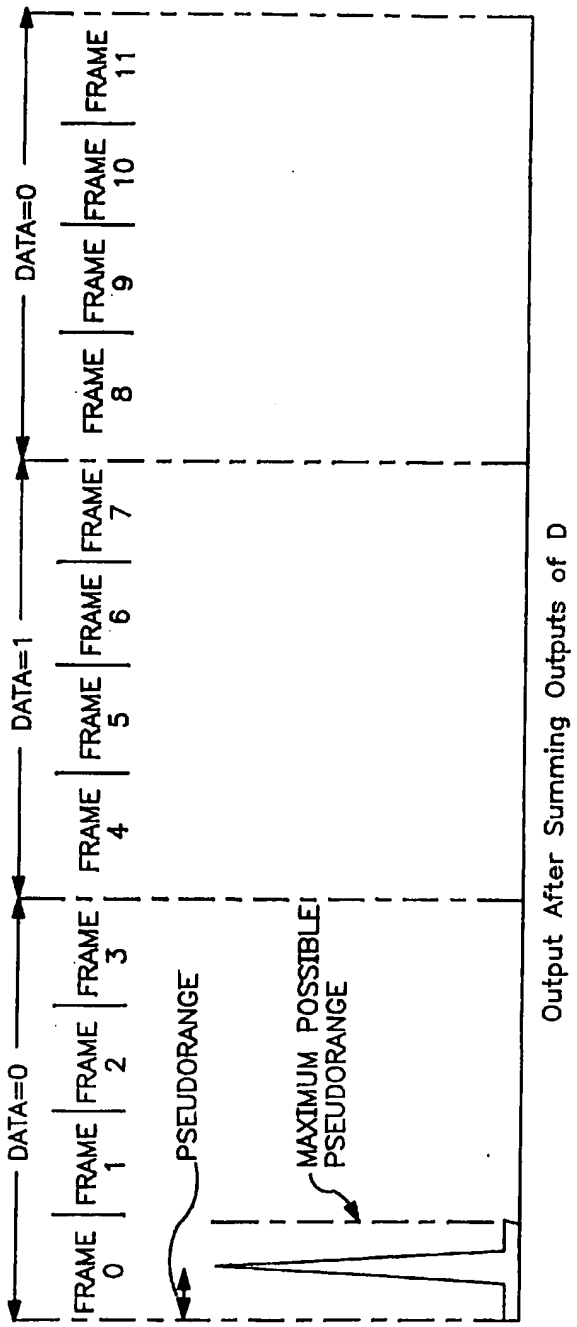
DATA=0
DATA=1
DATA=0
FRAME 0
FRAME 1
FRAME 2
FRAME 3
FRAME 4
FRAME 5
FRAME 6
FRAME 7
FRAME 8
FRAME 9
FRAME 10
FRAME 11
PSEUDORANGE
MAXIMUM POSSIBLE PSEUDORANGE
Output After Summing Outputs of D

FIG. 5E

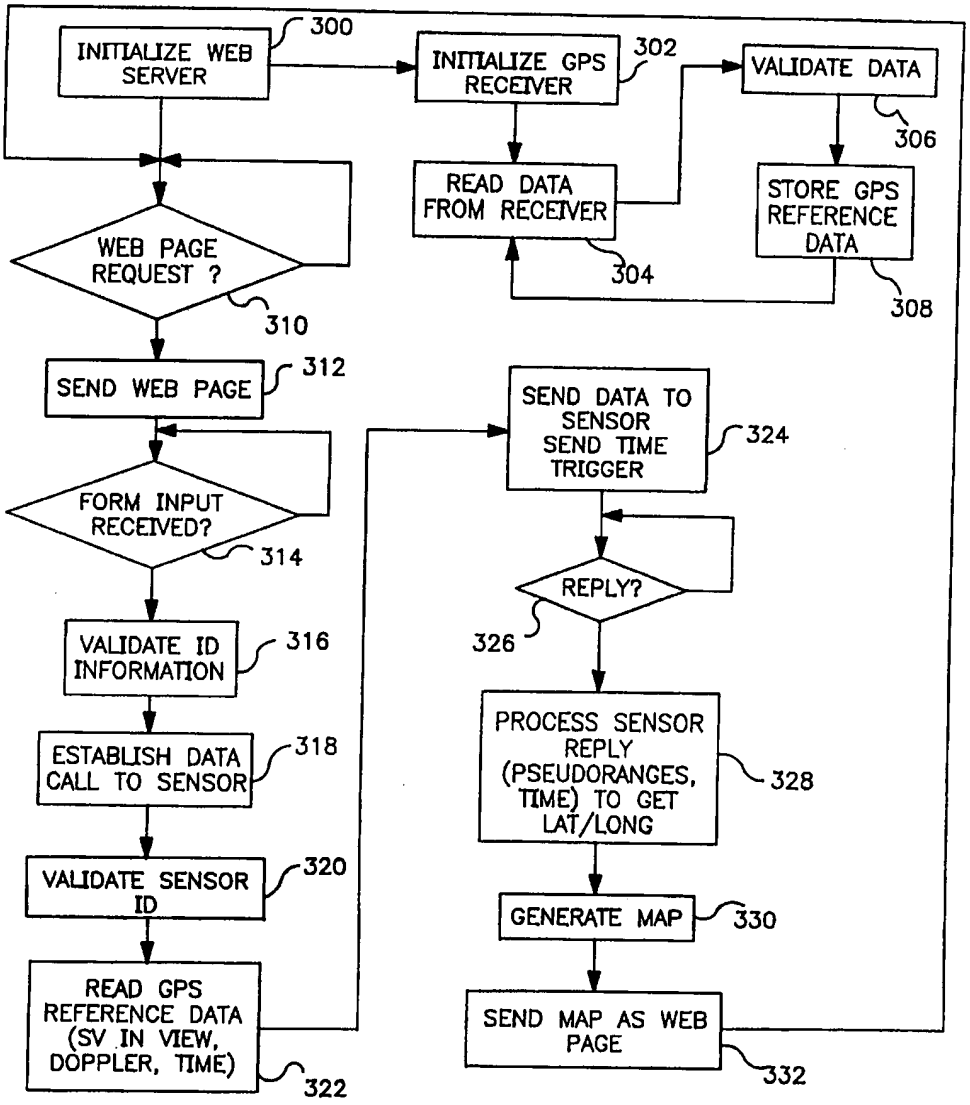
INITIALIZE WEB SERVER
300
INITIALIZE GPS RECEIVER
302
VALIDATE DATA
306
READ DATA FROM RECEIVER
304
STORE GPS REFERENCE DATA
308
WEB PAGE REQUEST ?
310
SEND WEB PAGE
312
FORM INPUT RECEIVED?
314
VALIDATE ID INFORMATION
316
ESTABLISH DATA CALL TO SENSOR
318
VALIDATE SENSOR ID
320
READ GPS REFERENCE DATA (SV IN VIEW, DOPPLER, TIME)
322
SEND DATA TO SENSOR SEND TIME TRIGGER
324
REPLY?
326
PROCESS SENSOR REPLY (PSEUDORANGES, TIME) TO GET LAT/LONG
328
GENERATE MAP
330
SEND MAP AS WEB PAGE
332

FIG. 6

CLIENT-SERVER BASED REMOTE LOCATOR DEVICE

RELATED APPLICATIONS

This application is related to and hereby claims the benefit of the filing date of a provisional patent application by one of the co-inventors, Norman F. Krasner, which application is entitled Low Power, Sensitive Pseudorange Measurement Apparatus and Method for Global Positioning Satellites Systems, Ser. No. 60/005,318, filed Oct. 9, 1995.

FIELD OF THE INVENTION

The present invention concerns client-server computer networks and the use of such networks to access remote sensors having associated position determination sensors.

BACKGROUND

Networking technology has developed a large network of networks, referred to as the Internet, which interconnects millions of computers around the world. The Internet allows the transfer of data between any number of computer systems connected to the Internet using the Transmission Protocol/Internet Protocol (TCP/IP). Computers responding to service requests from other computers, via the Internet, are commonly referred to as servers, and computers that initiate requests for service from a server are referred to as clients.

The Internet has become very popular in part due to the World Wide Web (WWW), which is a network of links to hypertext documents operating within the Internet. These hypertext documents are referred to as either Web documents, Web pages, or hypertext documents. Web documents are embedded with directly accessible connections or links to other documents which create a non-linear way of reading the document. The links are embedded in Web documents as a phrase of text or an image which can be selected and activated by a computer user. Information about the Web documents are controlled and provided by Web servers. At the user's end, a Web client takes the user's requests and passes them on to the Web server. A collection of related Web documents maintained by a single company or other entity is often referred to as a Web site.

The Web documents are written with a high level programming language referred to as the Hypertext Markup Language (HTML). Commands of the HTML, popularly known as tags, provide a variety of functions including, but not limited to, defining special format and layout information in a Web document, embedding images and sound in a Web document, and embedding links to other Web documents.

In order to access, process, and display a Web document, a client uses a set of instructions, referred to as a browser. The browser typically includes a set of browser commands corresponding to the tags available in the HTML. Each browser command in turn points to a procedure of one or more instructions defining the command which, when executed, provide a functionality of the respective command. If the client requires service from the Web server, the browser uses the Hypertext Transfer Protocol (HTTP) to communicate with the server.

The browser compares each tag found embedded in a Web document with the set of browser commands. Once a match is found, the browser executes the procedure corresponding to the match browser command in order to provide the functionality of the respective command.

Recently, some Web sites have begun offering users navigation-like aids. For example, some Web sites allow users to request the location of a tourist attraction or other location (e.g., a restaurant) and provide a map or a series of directions to the location in question. Often the Web sit provider will charge a user fee for this service or instead may charge a fee to the restaurant owners and others who wish to have the location of their business, etc. accessible in this manner. In this fashion, the Internet and the World Wide Web is becoming a useful tool for locating fixed sites. What is lacking, however, is a way for a user to locate a mobile remote object using such technology.

SUMMARY

One embodiment of the present invention provides a computer implemented method of determining the location of a remote sensor. In operation, a user accesses a server using a client. The client provides an identification code which serves to uniquely identify a remote sensor. The remote sensor is capable of providing information related to its position. The server then interrogates the remote sensor which is identified based on the identification code. In response, the remote sensor transmits positioning data to the server where it is analyzed to derive the location of the remote sensor. The location so determined is transmitted from the server to the client and is displayed at the client so that the user can identify the location of the remote sensor.

In this embodiment, the client and the server may be connected to a computer network and the client may use a web browser to interrogate the server. In general, the web browser provides a graphical user interface for the user. The computer network may be the Internet, a local area network or another data communications network. Where the Internet is used, the server may provide a web page having means for the user to identify the remote sensor.

In another embodiment, the present invention provides a method of determining the location of a remote sensor wherein a position signal having positioning data and an identification code is transmitted from a remote sensor to a server. The server receives the position signal and analyzes the signal to generate information representing the location of the remote sensor. The server transmits this location information to a client where the location information is displayed, thereby allowing a user to identify the location of the remote sensor.

In this embodiment, the position signal transmitted by the remote sensor may include an emergency code. The signal may be transmitted using a modulated radio frequency carrier or other transmission media.

The remote sensor may be a SNAPSHOT GPS receiver capable of obtaining a position fix in a relatively short period of time. Other GPS receivers or positioning devices could also be used.

The user display may be a simple position report, e.g., latitude and longitude, or a graphical report which provides an indication of the remote sensor's location superimposed on a map or other reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements and in which:

FIG. 1A is a block diagram of the major components of a computer implemented system for determining the location of a remote sensor utilizing the methods of the present invention;

FIG. 1B is a block diagram of an alternate embodiment of a computer implemented system for determining the location of a remote sensor utilizing the methods of the present invention;

FIG. 2 is a block diagram illustrating one embodiment of a SNAPSHOT GPS receiver for use according to the present invention;

FIGS. 3A and 3B provide two alternatives for the RF and IF portions of a snapshot GPS receiver for use according to the present invention;

FIG. 4 shows a flowgraph of the major software operations performed by a programmable DSP processor of a snapshot GPS receiver for use according to the present invention;

FIGS. 5A–5E illustrate a signal processing waveform at various stages of processing in a snapshot GPS receiver for use according to the present invention; and

FIG. 6 is an exemplary flow diagram for the server functions according to one embodiment of the present invention.

DETAILED DESCRIPTION

This invention concerns apparatus and methods for determining the position of a mobile, or remote, object using networks operating as clients and servers. One implementation of such a computer network is shown in FIG. 1A.

FIG. 1A illustrates a user having a laptop or other computer **1** connected to a computer network such as the Internet **5**. The Internet **5** is a large network of networks which interconnects millions of computers around the world. The user's computer **1** is connected to the Internet **5** via an Internet Service Provider **2**. The Internet Service Provider **2** is generally a server which allows a number of remote users to connect to the Internet **5** over telephone or other communication (e.g., ISDN) links. Users establish accounts with the Internet Service Provider **2** to allow access to the Internet **5** on demand, typically through a dial-up connection. Computer **1** will be recognized as a Web client or browser.

Also connected to Internet **5** through an Internet Service Provider **3** is base station **10** which includes a server **200**. Server **200** is connected to the Internet **5** via telephone lines and modem **202**. In alternative embodiments, server **200** may utilize ISDN or other data communication links to connect to Internet **5**. Also, server **200** may be directly connected to Internet **5**, without the need for Internet Service Provider **3**.

Server **200** will be recognized as a Web Server. As such, it provides hypertext or Web documents which can be accessed by computer **1**. These Web documents may be accessed directly through an Internet address associated with server **200** or by following links embedded in other Web documents as a phrase of text or an image which can be selected and activated by a computer user.

At the user's end, computer **1** includes a browser in order to access, process, and display Web documents. If the user requires service from server **200**, the browser uses the Hypertext Transfer Protocol (HTTP) or other suitable protocol to communicate with the server **200** over Internet **5** as described above.

In addition to server **200**, base station **10** includes a GPS receiver **204** with an associated GPS antenna **212**. GPS receiver **204** is a conventional GPS receiver capable of determining exact GPS time from in-view satellites. GPS receiver **204** provides current GPS time to server **200** and also provides a one pulse per second signal to Time Trigger **210** as described below.

In one embodiment, the location of GPS antenna **212** may be precisely determined using a survey or other means. Then, position information provided by GPS receiver **204** can be compared against the known location of GPS antenna **212** to produce position correction information at base station **10**. These position corrections can be applied to pseudoranges as Differential GPS (DGPS) corrections in order to precisely determine the location of GPS antenna **212** as is known in the art. As will be apparent upon review of this specification, however, the location of server **200** is not critical.

Base station **10** also includes a connection (e.g., modem **214**) to a cellular telephone transmitter site (cell site) **208**. Modem **214** is connected to server **200** to allow a telephone line connection to the cell site **208**. In other embodiments, an ISDN or other data communications link may be used. Time Trigger **210** is also connected to the communications link to cell site **208** and is under the control of server **200**. Time Trigger **210** provides a means of indicating time to a remote sensor **20** as described below. Cell site **208** has an associated antenna **214** which allows two-way communication with remote sensor **20**.

Remote sensor **20** includes a conventional cellular telephone **222** which is connected to a SNAPSHOT GPS receiver **220** and a time trigger **224**. The SNAPSHOT GPS receiver **220** is described in detail below. Briefly, SNAPSHOT GPS receiver **220** responds to commands from server **200**, which are transmitted across the cellular communication link provided by cell site **208** and cell phone **222**, to take a position fix using in-view GPS satellites. As described more fully below, the command from server **200** may also include Doppler prediction data regarding each of the in-view satellites. The Doppler information is collected by server **200** using GPS receiver **204**. This Doppler information allows SNAPSHOT GPS receiver **220** to obtain rapid position fixes as it eliminates the Doppler uncertainty those skilled in the art will appreciate in inherent in all GPS position calculations. Cellular telephone **222** may include a modem or other communication device appropriate for the method of data transmission used. Time trigger **224** provides means of identifying an accurate time stamp for a snapshot of data taken by SNAPSHOT GPS receiver **220**.

The command from server **200** may include a time trigger signal which provides the remote sensor **20** with an indication of the time. For example, sensor **200** may transmit a message which indicates that "at the tone, the time will be 'x'". This message is then followed by a tone generated by time trigger **210** in response to a control signal from server **200**. Of course, other time trigger signals may also be used. Notice that time trigger **210** is connected to GPS receiver **204**. Those skilled in the art will appreciate that GPS receivers such as GPS receiver **204** are capable of providing a very accurate timing reference output, for example, one pulse per second or fraction thereof. If such a timing reference signal is applied to time trigger **210**, say once per second, then time trigger **210** will generate a time trigger output signal once per second on a stable basis when enabled by server **200** through a control signal. When time trigger **210** then receives a control signal from server **200** indicating that the time trigger signal is to be transmitted to remote sensor **20**, the next time trigger signal generated (i.e., at the next one second interval as clocked by the output of GPS receiver **204**) will be transmitted via cell size **208** to remote sensor **20**.

Remote sensor **20** is able to use the received time trigger signal as the basis for initiating the collection of satellite data as described in detail below. Remote sensor **20** can then

compute pseudoranges from the collected satellite data using SNAPSHOT GPS receiver **220** as described in detail below.

When SNAPSHOT GPS receiver **220** has obtained pseudoranges to the in-view satellites, this information is transmitted to base station **10** across the cellular communications link. Accompanying this information may be a message which indicates how long since the receipt of the time trigger signal it has been. This "delta time" can be computed by remote sensor **20** using an onboard clock. Knowing the time difference between the original command to initiate a position fix and the time taken to collect and process the satellite data, server **200** can compute the location of remote sensor **20** in a customary fashion. The pseudorange information from remote sensor **20** may be processed along with DGPS correction information at server **200** in order to obtain the precise location of remote sensor **20**. Note that the DGPS correction information must be that for the general area in which remote sensor **20** is located. DGPS corrections are available for various area from various services, for example Differential Corrections, Inc., which provides such information for various areas of the United States. Such DGPS corrections could be used at server **200** to refine the position calculation for remote sensor **20**. The computed location of remote sensor **20** may then be transmitted via Internet **5** back to computer **1** where it is displayed for the user.

In summary, a user accesses server **200** using a computer **1**. As part of this access, the user may provide an identification code which serves to uniquely identify remote sensor **20**. Server **200** then interrogates the remote sensor **20** which is identified based on the identification code. In response, the remote sensor **20** transmits positioning data to the server **200** where it is analyzed to derive the location of the remote sensor **20**. The positioning data may be raw GPS data or, preferably, pseudoranges. The location of remote sensor **20** so determined is transmitted from server **200** to computer **1** and is displayed so that the user can identify the location of the remote sensor **20**.

In this embodiment, the client computer **1** and the server **200** have been described as being connected to the Internet **5**. However, computer **1** and server **200** may be connected to any computer network. Client computer **1** may use a web browser to interrogate server **200** as described above, other may use another method of computer communications. For example, upon receiving the connection from computer **1**, server **200** may download an applet across Internet **5** to computer **1** which, when executed by computer **1**, allows computer **1** to communicate with server **200**. Such an applet will, in general, provide a graphical use interface for the user to interface with server **200**.

Regardless of the implementation, the user will be provided with information regarding the use of the location service provided through server **200**. For example, the user may be required to provide a user name and password so that the user's preestablished account may be charged for the use of the service. Alternatively, the service may be provided as part of a user's cellular telephone or pager account. The user will also be provided with means to identify the remote sensor **20** of interest. Remote sensors may be identified by an identification code, such as the remote sensor's cellular telephone number or other unique identifying number. These identification numbers may be provided at the time a user subscribes to the location service.

The user display may be a simple position report, e.g., latitude and longitude, or a graphical report which provides an indication of the remote sensor's location superimposed on a map or other reference. In the latter situation, server **200** may have a geographical information system (GIS) application running which interfaces with the position information derived for remote sensor **20**. The position information so determined may be used to index the GIS data structure so that appropriate GIS information may be downloaded to the client computer **1**. For example, an appropriate section of a city map may be downloaded, with the location of the remote sensor highlighted on the map so that the user can easily identify the location of the remote sensor. It will be appreciated that such a location report provided by server **200** may be continuously updated by interrogating remote sensor **20** at various times and providing new position reports determined from these repeated interrogations to the client computer **1**. This may be accomplished in various ways, for example a user may successively "reload" the corresponding web page for an updated position report, or the web page may support a JAVA applet which continuously updates as long as the user remains connected to the web page. In this way the user may be provided with continuous updates regarding the location of remote sensor **20**. This information may be stored at computer **1** so as to provide a tracking plot of remote sensor **20**.

In another embodiment, illustrated in FIG. 1B, the present invention provides a method of determining the location of a remote sensor wherein a position signal having positioning data (e.g., raw GPG data or pseudoranges) and an identification code is transmitted from a remote sensor **20** to a server **200**. The server **200** receives the position signal and analyzes the signal to generate information representing the location of the remote sensor. The server transmits this location information to a client computer **220** where the location of remote sensor **20** is displayed, thereby allowing a user to identify the location of the remotes sensor **20**.

In this embodiment, the position signal transmitted by the remote sensor may also include an emergency code. For example, in the event of an emergency, such as a medical emergency or otherwise, a user may press a "panic button" found on the front panel of cell phone **222** or SNAPSHOT GPS receiver **220** (where these are separate units). Pressing the panic button may cause cell phone **222** to transmit an emergency signal to cell site **208** where the emergency signal is relayed to server **200**. In response, server **200** will transmit Doppler information regarding in-view satellites, a fix command and a time trigger signal to remote sensor **20** as described above, thereby allowing remote sensor **20** to compute pseudoranges to the in-view satellites. These pseudoranges are then relayed to server **200** as described above and used to compute the location of remote sensor **20**.

When the location of remote sensor **20** has been determined, software running on server **200** configures server **200** such that a call or other signal is sent to a local emergency operator in the vicinity of remote sensor **20**. This call or signal may be placed over a leased line, a standard telephone line, or via the Internet. When the call or signal is received at the emergency operator station, the location of remote sensor **20** is transmitted and displayed. In some cases, where separate panic buttons are available for identifying medical, police, fire or other types of emergencies, the nature of emergency is also displayed for the emergency operator. Based on this information, the emergency operator can initiate an emergency response by providing the location of the remote sensor **20** to the required emergency service (police, fire department, ambulance service, etc.). In other embodiments, instead of or in addition to a position report for the remote sensor **20**, the emergency operator may also be provided with information which identifies an emergency response vehicle in close proximity to remote sensor **20**.

Other embodiments of the present invention may allow for stolen vehicle tracking, inventory control, parental supervision of minors, monitoring of probationers, or other situations where accurate reporting of the location of a remote object are required. Although preferred embodiments of the present invention use SNAPSHOT GPS receivers, other positioning devices, such as conventional GPS receivers, could also be used.

FIG. **2** illustrates one embodiment of the remote sensor **20** which includes a SNAPSHOT GPS receiver. As described above, remote sensor **20** uses information transmitted from separately located base station **20** to assist in determining the position of the remote sensor **20**.

It should be noted that pseudoranges may be used to compute the remote's geographical position in many different ways. Three examples are:

Method 1: By retransmitting the satellite data messages to the remote sensor **20** from the base station **10**, the remote sensor **20** may combine this information with the pseudorange measurements to compute its position. See, for example, U.S. Pat. No. 5,365,450, which is incorporated herein by reference.

Method 2: The remote sensor **20** may gather the satellite ephemeris data from the reception of GPS signals in the normal manner that is commonly practiced in the art. This data, which typically is valid for one to two hours, may be combined with pseudorange measurements, typically in the remote sensor, to complete the position calculation.

Method 3: The remote sensor **20** may transmit over a communications link **16** the pseudoranges to the base station **10** which can combine this information with the satellite ephemeris data to complete the position calculation. See, for example, U.S. Pat. No. 5,225,842, which is incorporated herein by reference. This is a presently preferred method of operation.

In Methods 1 and 3, it is assumed that the base station **10** has information regarding the in-view satellites for remote sensor **20**. This may be the case where base station **10** and remote sensor **20** have a common view of all satellites of interest and are positioned close enough to one another to resolve a time ambiguity associated with the repetition rate of the GPS pseudorandom codes (approximately 150 km) or where base station **10** is provided with information regarding the approximate location of remote sensor **20** so that base station **20** can compute which satellites will be in-view for remote sensor **20**. If this latter arrangement is used, base station **10** may also require DGPS correction information appropriate for the location of remote sensor **20**.

For operation in accordance with Method 3 above, base station **10** may issue a command to perform a measurement via a message transmitted over data communications link **16**. The base station **10** also sends within this message Doppler information for the satellites in-view. This Doppler information typically is in the format of frequency information. This message is received by cell phone **222**, and it is stored in a memory **30** which is coupled to a low-power microprocessor **26**. The microprocessor **26** handles data information transfer between the remote sensor processing elements **32–48** which make up SNAPSHOT GPS receiver **200** and the cell phone **222**, and it controls power management functions within the remote receiver **20**, as will be evident in the subsequent discussion. Normally, microprocessor **26** sets some or all of the SNAPSHOT GPS receiver **220** hardware to a low power, or power down, state, except when the pseudorange and/or other GPS calculations are being performed, or when an alternative source of power is available.

The above-mentioned Doppler information is a relatively small number of bytes because the required accuracy of such Doppler information is not high. For example, if 10 Hz accuracy were required and the maximum Doppler is approximately ±7 kHz, then an 11 bit word would suffice for each satellite in view. If 8 satellites were in view, then 88 bits would be required to specify all such Dopplers. The use of this information eliminates the requirement for the remote sensor **20** to search for such Doppler, thereby reducing its processing time by in excess of a factor of 10. Additional information may also be sent to the remote sensor **20**, including the epochs of the data in the GPS message and the time trigger signal as discussed above.

The received data link signal may utilize a precision carrier frequency. The remote sensor **20** may employ an automatic frequency control (AFC) loop to lock to this carrier and thereby further calibrate its own reference oscillator. A message transmission time of 10 msec, with a received signal to noise ratio of 20 dB, will normally allow frequency measurement via an AFC to an accuracy of 10 Hz or better. This will typically be more than adequate for the requirements of the present invention.

For the embodiments described with reference to FIGS. **1A** and **1B**, the communication link **16** is a commercially available cellular telephone communications link. In other embodiments, narrow bandwidth communication links, such as two way pager links may be used. In this way, this system may be used in embodiments where the amounts of data to be transmitted between the base station **10** and the remote sensor **20** is relatively small (e.g., where base station **10** sends a command to remote sensor **20** to perform a position fix). In other embodiments, where the amount of data to be transferred between base station **10** and remote sensor **20** is relatively large, a higher bandwidth communication link **16** will be required.

Once the remote sensor **20** receives a command from the base station **10** for GPS processing together with the Doppler information, the microprocessor **26** activates RF to IF converter **42**, A/D Converter **44** and Digital Snapshot Memory **46** via a Battery and Power Control circuit **36**. This causes signals from the in-view GPS satellites to be received via antenna **40** and downconverted via RF to IF converter **42** to an IF frequency. The IF frequency signal is transferred to A/D converter **44** where it subsequently undergoes digitization. A contiguous set of such data, typically corresponding to a duration of 100 milliseconds to 1 second (or even longer), is then stored in a Snapshot Memory **46**. The addressing of this memory **46** is controlled by a Field Programmable Gate Array integrated circuit **48**. Downconversion of the GPS signal is accomplished using a frequency synthesizer **38** as discussed further below.

Note that all this time (while the snapshot memory **46** is being filled with the digitized GPS signals from the in-view satellites) DSP **32** may be in a low power state. The A/D Converter **44** need only be turned on for a short period of time, sufficient to collect and store the data required for pseudorange calculation. After the data collection is complete, these converter circuits together with the RF/IF downconverters are turned off, thus not contributing to additional power dissipation during the actual pseudorange calculation. The pseudorange calculation is then performed using, in one embodiment, a general purpose, programmable digital signal processing IC **32** (DSP), as exemplified by a TMS320C30 integrated circuit from Texas Instruments. This DSP **32** is placed in an active power state by the microprocessor **26** via the Battery and Power Control circuit **36** prior to performing such calculations.

This DSP **32** differs from others used in some remote GPS units in that it is general purpose and programmable, as compared to specialized custom digital signal processing IC's. Furthermore, the DSP **32** makes possible the use of a Fast Fourier Transform (FFT) algorithm, which permits very rapid computation of the pseudoranges by performing rapidly a large number of correlation operations between a locally generated reference and the received signals. Typically, 2046 such correlations are required to complete the search for the epochs of each received GPS signal. The Fast Fourier Transform algorithm permits a simultaneous and parallel search of all such positions, thus speeding the required computation process by a factor of 10 to 100 over conventional approaches.

Once the DSP **32** completes its computation of pseudoranges for each of the in-view satellites, it transmits this information to microprocessor **26**. At this time microprocessor **26** may cause DSP **32** to again enter a low power state by sending an appropriate control signal to the Battery and Power Control circuit **36**. Then, microprocessor **26** utilizes cell phone **222** to transmit the pseudorange data over data link **16** to the base station **10** for final position computation. In addition to the pseudorange data, a time tag may be simultaneously transmitted to base station **10**. The time tag indicates the elapsed time from the initial data collection in the buffer **46** to the time of transmission of the data over the data link **16**. This time tag improves the capability of the base station **10** to complete the position calculation because it allows the computation of the GPS satellite positions at the time of data collection. As an alternative, DSP **32** may compute the position (e.g., the latitude, longitude and, if required, the altitude) of the remote sensor **20** and send this data to the microprocessor **26**, which may similarly relay this data to the base station **10**, via cell phone **222**. This position computation may, alternatively be performed by microprocessor **26**, under program control.

As shown in FIG. **2**, cell phone **222**, in one embodiment, utilizes a separate antenna **24** to transmit and receive messages over data link **16**. Similarly, base station **10** may use a separate antenna **14** (such as the cell site antenna **214** described with reference to FIGS. **1A** and **1B**) to transmit and receive data link messages, thus allowing continuous reception of GPS signals via GPS antenna **212** at the base station **10**.

It is expected that the position calculations in the DSP **32** will require less than a few seconds of time, depending upon the amount of data stored in the digital snapshot memory **46** and the speed of DSP **32** or several DSPs.

It should be clear from the above discussion that the remote sensor **20** need only activate its high power consumption circuitry for a small fraction of time while in the snapshot mode, if position calculation commands are infrequent. The program commands necessary for the performance of the power management operation are stored in EEPROM **28** or other suitable storage media. This power management strategy may be adaptable to different power availability situations. For example, when prime power is available, the determination of position may occur on a continuing basis.

As indicated above, the digital snapshot memory **46** captures a record corresponding to a relatively long period of time. The efficient processing of this large block of data using fast convolution methods contributes to the ability of the present invention to process signals at low received levels (e.g., when reception is poor due to partial blockage from buildings, trees, etc.). All pseudoranges for visible GPS satellites are computed using this same buffered data. This provides improved performance relative to continuous tracking GPS receivers in situations (such as urban blockage conditions) in which the signal amplitude is rapidly changing.

Those skilled in the art will appreciate that the example shown in FIG. **2** is merely one possible implementation of a SNAPSHOT GPS receiver for use according to the present invention. Many other variations are possible in which various circuitry is shared between the snapshot GPS receiver and the cell phone **222**. In other cases, no circuitry may be shared, for example, where a SNAPSHOT GPS receiver is coupled to a conventional cellular telephone **222** via an RS-232 or similar coupling. Other embodiments may have a minimum of shared circuitry, for example, a common antenna. Still other embodiments may have a common processor performing all position computations for the GPS unit, and other functions for the cellular telephone or other communications unit. Other embodiments are shown and described ink detail in co-pending U.S. patent application Ser. No. 08/612,582, entitled "An Improved GPS Receiver Utilizing a Communications Link", filed Mar. 8, 1996 by Normal F. Krasner and assigned to the assignee of the present invention. Those skilled in the art will appreciate that all such alternatives are within the scope of the present invention and that the example shown in FIG. **2** is illustrative only. The remainder of this detailed description will assume that an embodiment such as that shown in FIG. **2** is used.

A representative example of an RF to IF frequency converter and digitizing system for SNAPSHOT GPS receiver **220** is shown in FIG. **3A**. The input signal 1575.42 MHz is passed through a bandlimiting filter (BPF) **50** and low noise amplifier (LNA) **52** and sent to a frequency conversion stage. The local oscillator (LO) **56** used in this stage is phase locked (via PLL **58**) to a 2.048 MHz (or harmonic thereof) temperature compensated crystal oscillator (TCXO) **60**. In a preferred implementation, the LO frequency would be 1531.392 MHz, which is 2991×0.512 MHz. The resulting IF signal is then centered at 44.028 MHz. This IF is desirable due to the availability of low cost components near 44 MHz. In particular, surface acoustic wave (SAW) filters, which are utilized in abundance in television applications, are readily available. Of course, other bandlimiting devices could be used instead of SAW devices.

The received GPS signal is mixed with the LO signal in mixer **54** to produce the IF signal. This IF signal is passed through a SAW filter **64**, for precision bandlimiting to 2 MHz bandwidth, and then sent to an I/Q down-converter **68**, which translates the signal to near baseband (4 kHz center frequency nominally). The local oscillator frequency for this downconverter **68** is derived from the 2.048 MHz TCXO **60** as the 43rd harmonic of 1.024 MHz, that is 44.032 MHz.

The I/Q downconverter **68** is generally commercially available as an RF component. It typically consists of two mixers and lowpass filters. In such instances, the input ports of one mixer are fed with the IF signal and the LO signal and the input ports to the other mixer are fed with the same IF signal and the LO signal phase shifted by 90°. The outputs of the two mixers are lowpass filtered to remove feedthrough and other distortion products.

As shown in FIG. **3A**, amplifiers **62** and **66** may be used before and after the bandlimiting operation as required.

The two outputs of the I/Q downconverter **68** are sent to two matched A/D converters **44** which sample the signals at 2.048 MHz. An alternative implementation replaces the A/D converters **44** with comparators (not shown), each of which

outputs a two-valued (one-bit) sequence of data in accordance with the polarity of the incoming signal. It is well known that this approach results in a loss of approximately 1.96 dB in receiver sensitivity relative to a multilevel A/D converter. However, there may be substantial cost savings in use of a comparator vs. A/D converters, as well as in the reduced memory requirement in the following snapshot memory **46**.

An alternative implementation of the downconverter and A/D system is shown in FIG. **3B** while utilizes a bandpass sampling method. The TCXO **70** employed is at frequency 4.096 MHz (or an harmonic thereof). The TCXO output may be used as the sample clock to the A/D converter **44** (or comparator); this acts to translate the signal to 1.028 MHz. This frequency is the difference between the 11th harmonic of 4.096 MHz and the input IF frequency 44.028 MHz. The resulting 1.028 MHz IF is nearly one-fourth the sample rate, which is known to be nearly ideal in minimizing sampling type distortions. As compared to the I/Q sampling of FIG. **3A**, this single sampler provides one channel of data rather than two, but at twice the rate. In addition, the data is effectively at an IF of 1.028 MHz. I/Q frequency conversion to near 0 MHz would then be implemented by digital means in the following processing to be described. The apparatus of FIGS. **3A** and **3B** are competitive in cost and complexity; often component availability dictates the preferred approach. It will be apparent to those skilled in the art, however, that other receiver configurations could be used to achieve similar results.

In order to simplify the following discussion, the following assumes that the I/Q sampling of FIG. **3A** is employed and that the snapshot memory **46** contains two channels of digitized data at 2.048 MHz.

Details of the signal processing performed in the DSP **32** may be understood with the aid of the flowgraph of FIG. **4** and the pictorial of FIGS. **5A–5E**. It will be apparent to those skilled in the art that the machine code, or other suitable code, for performing the signal processing to be described is stored in EPROM **34**. Other non-volatile storage devices could also be used. The objective of the processing is to determine the timing of the received waveform with respect to a locally generated waveform. Furthermore, in order to achieve high sensitivity, a very long portion of such a waveform, typically 100 milliseconds to 1 second, is processed.

In order to understand the processing, one first notes that each received GPS signal (C/A mode) is constructed from a high rate (1 MHz) repetitive pseudorandom (PN) pattern of 1023 symbols, commonly called "chips." These "chips" resemble the waveform shown in FIG. **5A**. Further imposed on this pattern is low rate data, transmitted from the satellite at 50 baud. All of this data is received at a very low signal-to-noise ratio as measured in a 2 MHz bandwidth. If the carrier frequency and all data rates were known to great precision, and no data were present, then the signal-to-noise ratio could be greatly improved, and the data greatly reduced, by adding to one another successive frames. For example, there are 1000 PN frames over a period of 1 second. The first such frame could be coherently added to the next frame, the result added to the third frame, etc. The result would be a signal having a duration of 1023 chips. The phasing of this sequence could then be compared to a local reference sequence to determine the relative timing between the two, thus establishing the so-called pseudorange.

The above process must be carried out separately for each satellite in view from the same set of stored received data in the snapshot memory **46**, since, in general, the GPS signals from different satellites have different Doppler frequencies and the PN patterns differ from one another.

The above process is made difficult by the fact that the carrier frequency may be unknown by in excess of 5 kHz due to signal Doppler uncertainty and by an additional amount due to receiver local oscillator uncertainty. These Doppler uncertainties are removed in one embodiment of the present invention by storing such information in RAM **30** as described above. Alternatively, Doppler information could be transmitted from base station **10**, which simultaneously monitors all GPS signals from in view satellites, in response to a signal via data link **16** indicating that remote sensor **20** had entered the snapshot mode. Thus, Doppler search is avoided at the remote sensor **20**. The local oscillator uncertainty can also be greatly reduced (to perhaps 50 Hz) by the aforementioned AFC operation performed using the base to remote communication signal.

The presence of 50 baud data superimposed on the GPS signal still limits the coherent summation of PN frames beyond a period of 20 msec. That is, at most 20 frames may be coherently added before data signal inversions prevent further processing gain. Additional processing gain may be achieved through matched filtering and summation of the magnitudes (or squares of magnitudes) of the frames, as detailed in the following paragraphs.

The flowgraph of FIG. **4** begins at step **100** with a command to initialize a snapshot GPS processing operation (termed a "Fix Command" in FIG. **4**). Where necessary, the command may include a transmission from remote sensor **20** to base station **10** for Doppler information for the in view satellites to be transmitted from base station **10** over data link **16**. At step **102**, the remote sensor **20** computes its local oscillator drift, for example, by frequency locking to the signal transmitted from the base station **10**. An alternative would be utilize a very good quality temperature compensated crystal oscillator in the remote sensor. For example, digitally controlled TCXOs, so-called DCXOs, currently can achieve accuracy of about 0.1 parts per million, or an error of about 150 Hz for the L1 GPS signal.

At step **104** the remote sensor's microprocessor **26** turns on power to the receiver front end **42**, Analog to Digital Converters **44** and digital snapshot memory **46**; and collects a snapshot of data of duration K PN frames of the C/A code, where K is typically 100 to 1000 (corresponding to 100 msec to 1 second time duration). When a sufficient amount of data has been collected, microprocessor **26** turns off the RF to IF converter **42** and the A/D converters **44**.

The pseudorange of each satellite is computed in turn as follows. First, at step **106** for the given GPS satellite signal to be processed, the corresponding pseudorandom code (PH) is retrieved from EPROM **34**. As discussed shortly, the preferred PN storage format is actually the Fourier transform of this PN code, sampled at a rate of 2048 samples per the 1023 PN bits.

The data in snapshot memory **46** is processed in blocks of N consecutive PN frames, that is blocks of 2048 N complex samples (N is an integer typically in the range 5 to 10). Similar operations are performed on each block as shown in the bottom loop (steps **108–124**) of FIG. **4**. That is, this loop is performed a total of K/N times for each GPS signal to be processed.

At step **108** the 2048 N data words of the block are multiplied by a complex exponential that removes the effects of Doppler on the signal carrier, as well as the effects of drifting of the receiver local oscillator. To illustrate, suppose the Doppler frequency obtained from the base station **10** plus local oscillator offsets correspond to f_e Hz. Then the

premultiplication of the data would take the form of the function $e^{-j2\pi f_e nT}$ n=[0, 1, 2, . . . 2048N−1]+(B−1)×2048N, where T=1/2.048 MHz is the sampling period, and the block number B ranges from 1 to K/N.

Next, at step **110**, the adjacent groups of N (typically 10) frames of data within the block are coherently added to one another. That is, samples 0, 2048, 4096, . . . 2048(N−1)−1 are added together, then 1, 2049, 4097, . . . 2048(N−1) are added together, etc. At this point the block contains only 2048 complex samples. An example of the waveform produced by such a summing operation is illustrated in FIG. **5**B for the case of 4 PN frames. This summing operation may be considered a preprocessing operation which precedes the fast convolution operations.

Next, at steps **112–118**, each of the averaged frames undergoes a matched filtering operation, which purpose is to determine the relative timing between the received PN code contained within the block of data and a locally generated PN reference signal. Simultaneously, the effects of Doppler on the sampling times is also compensated for. These operations are greatly speeded, in one embodiment, by the use of fast convolution operations such as Fast Fourier Transform (FFT) algorithms used in a manner to perform circular convolution, as presently described.

In order to simplify discussion, the above mentioned Doppler compensation is initially neglected.

The basic operation to be performed is a comparison of the data in the block being processed (2048 complex samples) to a similar reference PN block stored locally. The comparison is actually done by (complex) multiplying each element of the data block by the corresponding element of the reference and summing the results. This comparison is termed a "correlation." However, an individual correlation is only done for one particular starting time of the data block, whereas there are 2048 possible positions that might provide a better match. The set of all correlation operations for all possible starting positions is termed a "matched filtering" operation. The full matched filtering operation is required in a preferred embodiment.

The other times of the PN block can be tested by circularly shifting the PN reference and reperforming the same operation. That is, if the PN code is denoted p(**0**) p(**1**). . . p(**2047**), then a circular shift by one sample is p(**1**) p(**2**) . . . p(**2047**) p(**0**). This modified sequence tests to determine if the data block contains a PN signal beginning with sample p(**1**). Similarly the data block may begin with samples p(**2**), p(**3**), etc., and each may be tested by circularly shifting the reference PN and reperforming the tests. It should be apparent that a complete set of tests would require 2048×2048=4,194,304 operations, each requiring a complex multiplication and addition.

A more efficient, mathematically equivalent method may be employed, utilizing the Fast Fourier Transform (FFT), which only requires approximately 12×2048 complex multiplications and twice the number of additions. In this method, the FFT is taken for the data block, at step **112**, and for the PN block. The FFT of the data block is multiplied by the complex conjugate of the FFT of the reference, at step **114**, and the results are inverse Fourier transformed at step **118**. The resulting data so gotten is of length 2048 and contains the set of correlations of the data block and the PN block for all possible positions. Each forward or inverse FFT operation requires P/2 $\log_2$ P operations, where P is the size of the data being transformed (assuming a radix-2 FFT algorithm is employed). For the case of interest, P=2048, so that each FFT requires 11×1024 complex multiplications. However, if the FFT of the PN sequence is prestored in EPROM **34**, as in a preferred embodiment, then its FFT need not be computed during the filtering process. The total number of complex multiplies for the forward FFT, inverse FFT and the product of the FFTs is thus (2×11+2)×1024=24576, which is a savings of a factor of 171 over direct correlation. FIG. **5**C illustrates the waveform produced by this matched filtering operation.

The preferred method of the current invention utilizes a sample rate such that 2048 samples of data were taken over the PN period of 1023 chips. This allows the use of FFT algorithms of length 2048. It is known that FFT algorithms that are a power of 2, or 4, are normally much more efficient than those of other sizes (and 2048=2^{11}). Hence the sampling rate so chosen significantly improves the processing speed. It is preferable that the number of samples of the FFT equal the number of samples for one PN frame so that proper circular convolution may be achieved. That is, this condition allows the test of the data block against all circularly shifted versions of the PN code, as discussed above. A set of alternative methods, known in the art as "overlap save" or "overlap add" convolution may be utilized if the FFT size is chosen to span a number of samples different from that of one PN frame length. These approaches require approximately twice the number of computations as described above for the preferred implementation.

It should be apparent to one skilled in the art how the above process may be modified by utilizing a variety of FFT algorithms of varying sizes together with a variety of sample rates to provide fast convolutions operations. In addition, a set of fast convolution algorithms exist which also have the property that the number of computations required are proportional to P $\log_2$P rather than P^2 as is required in straightforward correlation. Many of these algorithms are enumerated in standard references, for example, H. J. Nussbaumer, "Fast Fourier Transform and Convolution Algorithms," New York, Springer-Verlag, ®1982. Important examples of such algorithms are the Agarwal-Cooley algorithm, the split nesting algorithm, recursive polynomial nesting algorithm, and the Winograd-Fourier algorithm, the first three of which are used to perform convolution and the latter used to perform a Fourier transform. These algorithms may be employed in substitution of the preferred method presented above.

The method of time Doppler compensation employed at step **116** is now explained. In the preferred implementation, the sample rate utilized may not correspond exactly to 2048 samples per PN frame due to Doppler effects on the received GPS signal as well as local oscillator instabilities. For example, it is known that the Doppler shift can contribute a delay error of ±2700 nsec/sec. In order to compensate for this effect, the blocks of data processed in the above description need to be time shifted to compensate for this error. As an example, if the block size processed corresponds to 5 PN frames (5 msec), then the time shift from one block to another could be as much as ±13.5 nsec. Smaller time shifts result from local oscillator instability. These shifts may be compensated for by time shifting the successive blocks of data by multiples of the time shift required by a single block. That is, if the Doppler time shift per block is d, then the blocks are time shifted by nd, n=0, 1, 2, . . .

In general these time shifts are fractions of a sample. Performing these operations directly using digital signal processing methods involves the use of nonintegral signal interpolation methods and results in a high computation burden. An alternative approach, that is a preferred method of the present invention, is to incorporate the processing within the fast Fourier transform functions. It is well-known

that a time shift of d seconds is equivalent to multiplying the Fourier Transform of a function by $e^{-j2\pi fd}$, where f is the frequency variable. Thus, the time shift may be accomplished by multiplying the FFT of the data block by $e^{-j2\pi nd/T_f}$ for n=0, 1, 2, . . . 1023 and by $e^{-j2\pi(n-2048)d/T_f}$ for n=1024, 1025, . . . , 2047, where T_f is the PN frame duration (1 millisecond). This compensation adds only about 8% to the processing time associated with the FFT processing. The compensation is broken into two halves in order to guarantee continuity of phase compensation across 0 Hz.

After the matched filtering operation is complete, the magnitudes, or magnitudes-squared, of the complex numbers of the block are computed at step **120**. Either choice will work nearly as well. This operation removes effects of 50 Hz data phase reversals (as shown in FIG. **5D**) and low frequency carrier errors that remain. The block of 2048 samples is then added to the sum of previous blocks processed at step **122**. Step **122** may be considered a post processing operation which follows the fast convolution operation provided by steps **122–188**. This continues until all K/N blocks are processed, as shown by the decision block at step **124**, at which time there remains one block of 2048 samples, from which a pseudorange is calculated. FIG. **5E** illustrates the resulting waveform after the summing operation.

Pseudorange determination occurs at step **126**. A peak is searched for above a locally computed noise level. If such a peak is found, its time of occurrence relative to the beginning of the block represents the pseudorange associated with the particular PN code and the associated GPS satellite.

An interpolation routine is utilized at step **126** to find the location of the peak to an accuracy much greater than that associated with the sample rate (2.048 MHz). The interpolation routine depends upon the prior bandpass filtering used in the RF/IF portion of the remote receiver **20**. A good quality filter will result in a peak having a nearly triangular shape with the width of the base equal to 4 samples. Under this condition, following subtraction of an average amplitude (to remove a DC baseline), the largest two amplitudes may be used to determine the peak position more precisely. Suppose these amplitudes are denoted A_p and A_{p+1}, where $A_p \geqq A_{p+1}$, without loss of generality, and p is the index of the peak amplitude. Then the position of the peak relative to that corresponding to A_p may be provided by the formula: peak location=$p+A_p/(A_p+A_p+A_{p+1})$. For example if $A_p=A_{p+1}$, then the peak location is found to be p+0.5, that is, halfway between the indices of the two samples. In some situations the bandpass filtering may round the peak and a three point polynomial interpolation may be more suitable.

In the preceding processing, a local noise reference used in thresholding may be computed by averaging all the data in the final averaged block, after removing the several largest such peaks.

Once the pseudorange is found, the processing continues at step **128** in a similar manner for the next satellite in view, unless all such satellites have been processed. Upon completion of the processing for all such satellites, the process continues at step **130** where the pseudorange data is transmitted to the base station **10** over communication (i.e., data) link **16**, where the final position calculation of the remote is performed (assuming Method 3 is utilized). Alternatively, the position calculation may be performed at remote sensor **20** using satellite ephemeris data transmitted from base station **10** and stored in RAM **30**. In such as embodiment, the computed position may be transmitted to base station **10** over data link **16**. Finally, at step **132**, the majority of the circuitry of the remote sensor **20** is placed in a low power state, awaiting a new command to perform another positioning operation.

In the foregoing embodiment, the processing of GPS signals from each satellite while in the snapshot mode occurs sequentially in time, rather than in parallel. In an alternative embodiment, the GPS signals from all in-view satellites may be processed together in a parallel fashion in time.

Referring now to FIG. **6**, an exemplary flow diagram illustrating the major processing operations performed by server **200** is shown. Beginning at step **300**, server **200** is initialized. As part of this process, server **200** activates GPS receiver **204** (step **302**) which begins to collect GPS data. As part of step **302**, GPS receiver **204** may compute the location of server **200**/base station **10** in order to produce DGPS corrections. When GPS data is available, server **200** reads the data at step **304**. This data may be validated (e.g., by comparing computed positions to known positions of server **200**) at step **306** and then stored at step **308**. The GPS data may include Doppler information for available GPS satellites for later use by remote sensors **20**. The process of reading, validating and storing GPS data is a continual one and may ran in the background on server **200** during all of the steps described below.

Server **200** remains in a wait state at step **310** until a request for Web page is received. The request may come from a remote user via the Internet as described above. When such a request is received, server **200** transmits Web page information to the client a step **312**.

As indicated above, the Web page may ask for user input. In such a case, server **200** waits at step **314** until such information is transmitted from the client. The information may be entered by a user filling out a form which is part of the Web page transmitted during step **312**.

When user input is received, server **200** attempts to validate any user identification (ID) information at step **316**. This may include accessing a user account data base maintained at server **200**, or perhaps remotely at a cellular telephone service provider location, in order to ensure that an authorized request for information is being attempted. Assuming the user information is valid, server **200** initiates a data call to remote sensor **20** at step **318**. This data call may require a separate sensor ID validation step **320** where a remote sensor **20** transmits a sensor ID and server **200** checks to ensure that the remote sensor **20** which responded to the data call is the remote sensor **20** which corresponds to the original user request.

When the server **200** has verified that it is in communication with the correct remote sensor **20**, server **200** reads the previously stored GPS data at step **322** and then transmits the data (e.g., satellites in-view, Doppler, etc.) along with a time trigger at step **324** as discussed in detail above. Once this information has been sent to the remote sensor **20**, server **200** waits at step **326** for a reply.

When the reply (e.g., pseudoranges) is received from remote sensor **20**, server **200** uses the reply data to compute the location of remote sensor **20** at step **328** as discussed above. When the location of remote sensor **20** has been computed, this information may be used at step **330** to generate a map which graphically illustrates the location of remote sensor **20**. The map may be part of a GIS data base maintained at server **200** as mentioned above. Once generated, the map, showing the location of remote sensor **20**, may be transmitted from server **200** to the client as a Web page at step **332**. Upon completion of this operation, server **200** again waits for a Web page request at step **310**.

Although the methods and apparatus of the present invention have been described with reference to GPS satellites, it will be appreciated that the teachings are equally applicable

to positioning systems which utilize pseudolites or a combination of satellites and pseudolites. Pseudolites are ground based transmitters which broadcast a PRN code (similar to a GPS signal) modulated on an L-band carrier signal, generally synchronized with GPS time. Each transmitter may be assigned a unique PRN code so as to permit identification by a remote receiver. Pseudolites are useful in situations where GPS signals from an orbiting satellite might be unavailable, such as tunnels, mines, buildings or other enclosed areas. The term "satellite", as used herein, is intended to include pseudolite or equivalents of pseudolites, and the term GPS signals, as used herein, is intended to include GPS-like signals from pseudolites or equivalents of pseudolites.

It will be further appreciated that the methods and apparatus of the present invention are equally applicable for use with the GLONASS and other satellite-based positioning systems. The GLONASS system differs from the GPS system in that the emissions from different satellites are differentiated from one another by utilizing slightly different carrier frequencies, rather than utilizing different pseudorandom codes. In this situation, substantially all the circuitry and algorithms described above are applicable, with the exception that when processing a new satellite's emission, a different complex exponential multiplier is used to preprocess the data. The operation may be combined with the Doppler correction operation of step **108** of FIG. **4**, without requiring any additional processing operations. Only one PN code is required in this situation, thus eliminating step **106**.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A computer implemented method of determining the location of a mobile remote sensor, the method comprising the steps of:

accessing a server using a client, said client being remote from said server;

providing an identification code from said client to said server, said identification code uniquely associated with said remote sensor;

interrogating said remote sensor from said server based on said identification code;

transmitting positioning data from said remote sensor to said server in response to said step of interrogating;

analyzing said positioning data at said server to produce processed positioning information, said processed positioning information representing the location of said remote sensor;

transmitting said processed positioning information from said server to said client; and

displaying said processed positioning information at said client so that a user can identify the location of said remote sensor.

2. The computer implemented method of claim **1** wherein said client and said server are connected to a computer network and wherein said step of accessing further comprises the step of:

using a web browser to interrogate said server, said web browser providing a graphical user interface for said user at said client.

3. The computer implemented method of claim **2** wherein said computer network is the Internet and wherein said step of accessing further comprises the step of:

providing a web page from said server to said client after said web browser interrogates said server.

4. The computer implemented method of claim **3** wherein said web page provides means for said user to identify said remote sensor and wherein said step of providing an identification code further comprises the step of:

transmitting said identification code from said client to said server using said means for said user to identify said remote sensor.

5. The computer implemented method of claim **4** wherein said server is associated with a communication station and wherein said step of interrogating said remote sensor further comprises the steps of:

receiving said identification code at said server;

identifying said remote sensor based on said identification code;

transmitting an interrogation signal to said remote sensor using said communication station.

6. The computer implemented method of claim **5** wherein said remote sensor comprises a SNAPSHOT GPS receiver and said server is further associated with a GPS base station and wherein said step of interrogating said remote sensor further comprises the step of:

transmitting from said server to said remote sensor Doppler information regarding in-view satellites using said communication station.

7. The computer implemented method of claim **5** wherein said remote sensor comprises a GPS receiver and wherein said step of transmitting positioning data further comprises the steps of:

receiving said interrogation signal at said remote sensor;

computing said positioning data at said remote sensor;

transmitting said positioning data from said remote sensor to said server.

8. The computer implemented method of claim **7** wherein said positioning data comprises pseudoranges.

9. The computer implemented method of claim **7** wherein said positioning data comprises a latitude and longitude.

10. The computer implemented method of claim **7** wherein said positioning data comprises a latitude, a longitude and an altitude.

11. The computer implemented method of claim **6** wherein said positioning data comprises pseudoranges.

12. The computer implemented method of claim **6** wherein said positioning data comprises a latitude and a longitude.

13. The computer implemented method of claim **6** wherein said positioning data comprises a latitude, a longitude and an altitude.

14. The computer implemented method of claim **7** wherein said remote sensor comprises a SNAPSHOT GPS receiver and wherein said interrogation signal includes Doppler information regarding in-view satellites.

15. The computer implemented method of claim **7** wherein said interrogation signal includes differential GPS corrections.

16. The computer implemented method of claim **7** wherein said step of analyzing further comprises the steps of:

receiving said positioning data at said server; and

associating said positioning data with a digital map to produce said processed positioning information, said

processed positioning information comprising a graphical representation of the location of said remote sensor.

17. The computer implemented method of claim 7 wherein said step of analyzing further comprises the steps of:

receiving said positioning data at said server; and

applying differential corrections to said positioning data to produce said processed positioning information.

18. The computer implemented method of claim 7 wherein said positioning data comprises pseudoranges and wherein said step of analyzing further comprises the steps of:

receiving said positioning data at said server; and

computing said processed positioning information at said server using said positioning data.

19. The computer implemented method of claim 18 wherein said step of computing said processed positioning information further comprises the step of applying differential GPS corrections to said positioning data.

20. The computer implemented method of claim 2 wherein said computer network is a private network and wherein said step of accessing further comprises the step of:

providing a web page from said server to said client after said web browser interrogates said server.

21. The computer implemented method of claim 20 wherein said web page provides means for said user to identify said remote sensor and wherein said step of providing an identification code further comprises the step of:

transmitting said identification code from said client to said server using said means for said user to identify said remote sensor.

22. The computer implemented method of claim 21 wherein said server is associated with a communication station and wherein said step of interrogating said remote sensor further comprises the steps of:

receiving said identification code at said server;

identifying said remote sensor based on said identification code;

transmitting an interrogation signal to said remote sensor using said communication station.

23. The computer implemented method of claim 22 wherein said remote sensor comprises a snapshot GPS receiver and said server is further associated with a GPS base station and wherein said step of interrogating said remote sensor further comprises the step of:

transmitting from said server to said remote sensor Doppler information regarding in-view satellites using said communication station.

24. The computer implemented method of claim 22 wherein said remote sensor comprises a GPS receiver and wherein said step of transmitting positioning data further comprises the steps of:

receiving said interrogation signal at said remote sensor;

computing said positioning data at said remote sensor;

transmitting said positioning data from said remote sensor to said server.

25. The computer implemented method of claim 24 wherein said positioning data comprises pseudoranges.

26. The computer implemented method of claim 24 wherein said positioning data comprises a latitude and longitude.

27. The computer implemented method of claim 24 wherein said positioning data comprises a latitude, a longitude and an altitude.

28. The computer implemented method of claim 23 wherein said positioning data comprises pseudoranges.

29. The computer implemented method of claim 23 wherein said positioning data comprises a latitude and a longitude.

30. The computer implemented method of claim 23 wherein said positioning data comprises a latitude, a longitude and an altitude.

31. The computer implemented method of claim 24 wherein said remote sensor comprises a SNAPSHOT GPS receiver and wherein said interrogation signal includes Doppler information regarding in-view satellites.

32. The computer implemented method of claim 24 wherein said interrogation signal includes differential GPS corrections.

33. The computer implemented method of claim 24 wherein said step of analyzing further comprises the steps of:

receiving said positioning data at said server; and

associating said positioning data with a digital map to produce said processed positioning information, said processed positioning information comprising a graphical representation of the location of said remote sensor.

34. The computer implemented method of claim 24 wherein said step of analyzing further comprises the steps of:

receiving said positioning data at said server; and

applying differential corrections to said positioning data to produce said processed positioning information.

35. The computer implemented method of claim 24 wherein said positioning data comprises pseudoranges and wherein said step of analyzing further comprises the steps of:

receiving said positioning data at said server; and

computing said processed positioning information at said server using said positioning data.

36. The computer implemented method of claim 35 wherein said step of computing said processed positioning information further comprises the step of applying differential GPS corrections to said positioning data.

37. The computer implemented method of claim 16 wherein said processed positioning information comprises a GIF format document.

38. The computer implemented method of claim 16 wherein said processed positioning information comprises a JPEG format document.

39. The computer implemented method of claim 33 wherein said processed positioning information comprises a GIF format document.

40. The computer implemented method of claim 33 wherein said processed positioning information comprises a JPEG format document.

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